Docket No. 245389US2CRL/hyc

OIPE JC26 APR 2 6 2004 PATENT & TRADEMARK OFFICE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

IN RE APPLICATION OF: ~~Steve~~ C. J. PARKER GAU:

SERIAL NO: 10/713,193 EXAMINER:

FILED: November 17, 2003

FOR: METHOD AND APPARATUS FOR INCREASING THE NUMBER OF STRONG EIGENMODES IN A MULTIPLE-INPUT MULTIPLE-OUTPUT (MIMO) RADIO CHANNEL

REQUEST FOR PRIORITY

COMMISSIONER FOR PATENTS
ALEXANDRIA, VIRGINIA 22313

SIR:

☐ Full benefit of the filing date of U.S. Application Serial Number , filed , is claimed pursuant to the provisions of **35 U.S.C. §120**.

☐ Full benefit of the filing date(s) of U.S. Provisional Application(s) is claimed pursuant to the provisions of **35 U.S.C. §119(e)**: **Application No.** **Date Filed**

■ Applicants claim any right to priority from any earlier filed applications to which they may be entitled pursuant to the provisions of **35 U.S.C. §119**, as noted below.

In the matter of the above-identified application for patent, notice is hereby given that the applicants claim as priority:

COUNTRY	APPLICATION NUMBER	MONTH/DAY/YEAR
UNITED KINGDOM	0230030.9	December 21, 2002

Certified copies of the corresponding Convention Application(s)

- ■ are submitted herewith
- ☐ will be submitted prior to payment of the Final Fee
- ☐ were filed in prior application Serial No. filed
- ☐ were submitted to the International Bureau in PCT Application Number
  Receipt of the certified copies by the International Bureau in a timely manner under PCT Rule 17.1(a) has been acknowledged as evidenced by the attached PCT/IB/304.
- ☐ (A) Application Serial No.(s) were filed in prior application Serial No. filed ; and
- ☐ (B) Application Serial No.(s)
  - ☐ are submitted herewith
  - ☐ will be submitted prior to payment of the Final Fee

Respectfully Submitted,

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(OSMMN 05/03)

10/713,193

The Patent Office
Concept House
Cardiff Road
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South Wales
NP10 8QQ

INVESTOR IN PEOPLE

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation and Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein together with the Statement of inventorship and of right to grant of a Patent (Form 7/77), which was subsequently filed.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

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Signed

Dated 25 November 2003

Patents Form 1/77

Patents Act 1977
(Rule 16)

THE PATENT OFFICE
K
23 DEC 2002

The Patent Office

270EC02 E773385-1 D03312
P01/7700 0.00-0230030.9

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

THE PATENT OFFICE
21 DEC 2002
EFFECTIVE DATE

21 DEC 2002

The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

1. Your reference GBP87173

2. Patent application number (The Patent Office will fill in this part) 0230030.9

3 Full name, address and postcode of the or of each applicant (underline all surnames)

Toshiba Research Europe Limited,
32 Queen Square
Bristol BS1 4ND
United Kingdom

Patents ADP number (if you know it) 08114095001

If the applicant is a corporate body, give the country/state of its incorporation: United Kingdom

4. Title of the invention

Method and Apparatus for Increasing the Number of Strong Eigenmodes Multiple-Input Multiple-Output (MIMO) Radio Channel

5. Name of your agent (if you have one)
"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

Marks & Clerk
57 - 60 Lincolns Inn fields
London WC2A 3LS

Patents ADP number (if you know it) 18001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country	Priority application No (if you know it)	Date of filing (day / month / year)

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing (day / month / year)

8. Is a statement of inventorship and of right to grant of a patent required in support ofthis request? (Answer 'Yes' if:
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
See note (d)) Yes

Patents Form 1/77

9. Ent[illegible]e number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	0
Description	7
Claim(s)	4
Abstract	1
Drawing(s)	2 + 2

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77)

Request for substantive examination (Patents Form 10/77)

Any other documents (please specify)

11. I/We request the grant of a patent on the basis of this application.

Marks & Clerk

Signature

Date: 20 December 2002

12. Name and daytime telephone number of person to contact in the United Kingdom

GB Patent Filings
0207 400 3000

Patents Form 7/77

Patents Act 1977
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The
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The Patent Office

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NP9 1RH

Statement of inventorship and of right to grant of a patent

THE PATENT OFFICE
15 AUG 2003
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18AUG03 B140168-1 003312
P07/7700 0.00-0230030.9

1. Your reference — GBP87173

2. Patent application number *(if you know it)* — 0230030.9

3. Full name of the or of each applicant — Toshiba Research Europe Limited,

4. Title of the invention — Method and Apparatus for Increasing the Number of Strong Eigenmodes in a Multiple-Input Multiple-Output (MIMO) Radio Channel

5. State how the applicant(s) derived the right from the inventor(s) to be granted a patent — By virtue of employment

6. How many, if any, additional Patents Forms 7/77 are attached to this form? *(see note (c))*

7. I/We believe that the person*(s)* named over the page *(and on any extra copies of this form)* is/are the inventor*(s)* of the invention which the above patent application relates to.

Signature — Date

MKC — 15 August 2003

8. Name and daytime telephone number of person to contact in the United Kingdom — GB Patent Filing section — 0207 400 3000

Notes

a) If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.
b) Write your answers in capital letters using black ink or you may type them.
c) If there are more than three inventors, please write the names and addresses of the other inventors on the back of another Patents Form 7/77 and attach it to this form.
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e) Once you have filled in the form you must remember to sign and date it.

Enter the full names, addresses and postcodes of the inventors in the boxes and underline the surnames

Parker, Steve Carl Jamieson
c/o Toshiba Research Europe Limited
32 Queen Square
Bristol BS1 4ND

07748346002

Patents ADP number (if you know it):

Reminder
Have you signed the form?

Method and Apparatus for Increasing the Number of Strong Eigenmodes in a Multiple-Input Multiple-Output (MIMO) Radio Channel

The present invention relates to communication systems and more particularly to systems utilising the Multiple-Input Multiple-Output (MIMO) radio channel communication method.

Conventional communication systems have relied upon a single antenna transmitter and single antenna receiver system. However, such systems have a capacity which is fundamentally limited for a given bandwidth and signal-to-noise ratio of the received signal. The use of multiple antennas at the receiver and transmitter (MIMO) extends the system into the spatial domain and fundamentally increases its capacity. A system may then be designed which has a larger potential throughput. A system which has equal numbers of transmit and receive antennas has an inherent capacity which scales approximately linearly with the number of antennas. This is achieved by reuse of the same temporal/spectral channel using independent spatial propagation modes that may be separated at the receiver through signal processing. Consequently such radio systems are becoming increasingly important.

However, the linear relationship between antenna number and fundamental capacity is an over-simplification. In practice, to realise this potential capacity, the receiver has the task of separating the interfering spatial sub-channels. This requires the receiver to determine a sufficient number of independent equations which may be solved to isolate the spatial sub-channels. With current systems, this requires that several unique spatial propagation modes, known as eigenmodes, exist which connect the transmitter and receiver. If the number of strong eigenmodes is lower than the number of transmit (or receive elements) then the potential capacity of the system is reduced.

A channel contains a large number of spatial eigenmodes when there are a large number of rays with a large angular separation that connect the transmitter and the receiver. This

situation occurs when a number of scatterers, i.e. objects causing scattering of the transmitted signal, are located around the antennas. Figure 1 shows how the performance of an uncoded BLAST (Bell Labs Layered Space-Time) architecture, with 6x8 MIMO channel, is degraded (bit error rate (BER) increases) when the angular diversity is small. These results were obtained using a wide sense stationary uncorrelated scattering (WSSUS) channel model. An aim of the present invention is to reduce the performance difference between these two extremes.

Digital beamforming can be used to increase the spatial separation of signals (or to increase the angular acceptance of the receive array). However, this system requires complex digital processing electronics for conditioning the signals prior to feeding to the antenna array for transmission.

With current MIMO systems, there is a danger than the potential throughput may not be achieved in a given environment where sufficiently strong eigenmodes cannot be established to support the multiplexed spatial sub-channels. Consequently, there is a danger that such a system may perform no better or potentially worse than a single antenna system. Thus the considerable investment in a multi-antenna system may not provide any return.

Therefore according to the present invention there is provided a transceiver comprising: an antenna array having a plurality of antennas and a scattering structure associated with the antennas for receiving the signals from the antennas. The invention also provides a transceiver comprising: an antenna array having a plurality of antennas; and a scattering structure associated with the antennas for receiving incoming signals and passing them on to the array of antennas.

The scattering structure scatters the signals from the transmit antenna array to provide good angular diversity at a receiver. Similarly, a scattering structure may be used at the receiver to increase the angular acceptance of the receive array. Potentially this can provide good decorrelation between each of the sub-channels without adversely affecting the power throughput.

The present invention preferably includes a scattering or waveguide structure or structures which may be dynamically adjusted to vary the eigenmodes established between the transmitter and receiver. In this way, the throughput may be improved by varying the scattering in the hope of establishing stronger eigenmodes. Preferably, the transceiver includes a controller for controlling the scattering structure. Ideally, the controller receives information fed back from the receiver to determine whether and how to adjust the scattering structure.

The scattering structure may achieve scattering of the beams from the antennas in any number of ways including, for example, by diffraction, reflection, scattering or refraction, or a combination of them.

In one embodiment, the structure may be formed as a diffraction grating for diffracting the beams. This may be formed from a series of slits formed in a sheet of material, wherein the slits have a different refractive index or absorption coefficient to the spaces between the slits. The slits are preferably adjustable, in their spacing or shape, to provide the adjustment function. Beneficially, two or more diffraction gratings may be used in series to provide further control over the diffraction process. One or more of these may be adjustable.

The present invention also provides a method of scattering signals produced by an array of antennas, the method comprising: interposing a scattering structure between the antennas and a receiver to scatter the beams produced by the antennas, receiving feedback information concerning the strength of the eigenmodes established between the antennas and a receiver; and adjusting the scattering structure to vary the scattering of the beams produced by the antennas.

The present invention relies upon the importance of having diverse paths or eigenmodes between the transmitter and receiver. This is in contrast to traditional single antenna systems where multipath is problematic and so normally avoided.

The present invention provides a system which provides high capacity, by searching out the best propagation modes that exist in any given environment. This is achieved

without the need for complex and expensive circuitry such as that used for digital or analogue beamforming. The present invention instead utilises a simple structure, which is separate from the main antenna thereby providing more degrees of freedom for optimisation, to provide an eigenmode rich channel regardless of the local environment. This will allow a lower cost system with simpler installation since the installer need pay less attention to the radio environment and so the location of the access point.

The arrangement of the present invention also allows for the possibility of three-dimensional packing of antennas.

The present invention will now be described in more detail with reference to the attached drawings in which:-

Figure 1 is a graph showing the affect of angular diversity on the performance of an uncoded BLAST system; and

Figure 2 shows a schematic embodiment of a communication system of the present invention.

Figure 2 shows schematically an arrangement of an embodiment of the present invention. Although the system is a bidirectional system, the following description will concentrate only on communication in one direction with the transceiver 10 on the left acting as transmitter and the transceiver 20 on the right acting as receiver. Figure 2 shows a scattering structure 13 arranged adjacent to the array of antennas 12. No scattering structure is shown for the receiver although one could be provided if desired although this is not essential.

In a real-world environment, such as in an office, an access point (AP) is typically located in a convenient location to prevent inconvenience to users. Typically these are mounted on a ceiling. In contrast terminals, particularly mobile terminals, are often located amongst everyday objects of an office. Consequently, the terminals will normally be surrounded by scatterers and the diversity of signals will be sufficient. In contrast, the AP is located away from any scatterers and so signals emanating from it

are unlikely to encounter scatterers in its proximity. In this example, the present invention can be applied to the AP to improve the angular spatial diversity and hence achieve a throughput which is closer to the theoretical maximum channel capacity. Using this example, the AP is represented by the transmitter 10 and the mobile terminal by the receiver 20.

In use, the transmitter processes the signal to be transmitted and divides this up into the various sub-channels ready for transmission by respective antennas 12. The signals are fed to the antennas 12 of the array to transmit the signal. The scattering structure 13 in this embodiment is a diffraction grating although any structure which causes scattering of the incident signals could be used. The signals impinge on the diffraction grating causing scattering. This scattering can be controlled to couple energy into the strongest spatial eigenmodes supported by the channel.

In figure 2 the diffraction grating is shown as a single structure. The grating may be a single structure or formed from a number of separate gratings. The antenna array 12 may adopt many different geometries, such as linear, planar or circular and the grating may be formed into a structure surrounding the antennas. As indicated above, the grating may consist of a regular periodic structure or it may have a more complex structure to diffract the incident energy in a designed way (e.g. several diffraction orders of nominally equal strength). The scattering structure is shown in figure 2 located in close proximity to the antenna array (but far enough away to be in far-field of the antennas). This is practically convenient in terms of providing a convenient package. In this way, the structure could be located near the antenna array module in a convenient joint housing.

The transmission diffraction grating of this embodiment, located at the aperture of the receiving antenna module, is used to split the incident beam into several diffraction orders which would have angular diversity. A second grating can be used to further spread the incident beam so that, from the perspective of the receiver antenna elements, the incident beam has emanated from several virtual source points located around the receiver.

Once the transmitted signals from the antennas have passed through the scattering structure, they are received by the antennas 22 at the receiver, e.g. a mobile terminal. The receiver 20 decodes the received signal to determine the quality of the eigenmodes established between the transmitter and the receiver. The receiver can then transmit the determined quality information back to the transmitter 10. The quality information is extracted and used to adjust the scattering structure. The controller 14 then receives this information and adjusts the scattering structure to modify the grating and thereby vary the eigenmodes developed. For example, the slot spacing and size may be physically modified to bring about a variation in the eigenmodes.

In order to maximise the throughput, the system must establish eigenmodes which have good power efficiency. If weak eigenmodes are established then their poor power transmission will reduce the inherent capacity of that sub-channel. Furthermore, if the terminal moves or objects within the environment move then the transmission paths may change significantly and so dynamic control over the established eigenmodes helps to overcome this. In this way, the signals fed back from the receiver allow the scattering structure to be adjusted to establish strong eigenmodes with high fundamental capacity. By monitoring the received signals and feeding back information from the receiver, the controller 14 can adjust the established modes to maintain high throughput.

As indicated above, a second diffraction grating may be used to further enhance the angular diversity of the signals passing through it. However, this could be taken further and three or more gratings may be used. In order to adjust the eigenmodes developed by the system one or more of such gratings may be adjustable to allow increased flexibility. Furthermore, the scattering structure could be divided up into separate sections, each individually adjustable.

The embodiment described above uses a diffraction grating to increase the angular diversity of the signals passing through it. However, the invention is equally applicable for use with other scattering elements which reflect, refract, diffract or otherwise scatter the incident beam. Furthermore, a combination of devices may be used to perturb the incident radiation.

The above embodiment has been described in respect of transmission primarily in one direction. However, the system is fully capable of operating in reverse with the unit 20 transmitting to the unit 10. The signals impinge on the scattering structure in a similar way albeit form the antennas 22 but the effect is still provided so that the antennas 12 'see' the transmitting antennas as spaced apart virtual sources. As indicated, feedback information would be provided to the transceiver with the scattering structure to allow dynamic adjustment. Again, if both transceivers are provided with a scattering structure, then feedback information can be passed in both directions.

The present invention can also be used overcome an interferer. If an interferer is affecting the reception of a sub-channel, the scattering structure can be adjusted to modify the eigenmodes and so avoid using the sub-channel suffering the interference. In this way the interfering signal can be rejected by the receiver.

The present invention has been described primarily in respect of providing a scattering structure adjacent to the transmitting antenna array. However, the principles of the present invention can be applied where the scattering structure is provided adjacent to the receiving antenna. In this way, rather than providing angular diversity as the signals leave the transmitter structure, the scattering structure effectively defines angularly diverse receive paths for the receiver. This ensures that signals received from the transmitter are angularly diverse, thereby enhancing the capacity of the system.

In this arrangement, the scattering structure can be controlled in a similar way to optimise the eigenmodes between the transmitter and the receiver.

CLAIMS:

1. A transceiver comprising:
an antenna array having a plurality of antennas; and
a scattering structure associated with the antennas for receiving the signals from the antennas.

2. A transceiver according to claim 1, wherein the scattering structure is a passive structure.

3. A transceiver according to claim 1 or 2, wherein the scattering property of the scattering structure can be externally adjusted.

4. A transceiver according to claim 1, 2 or 3, further comprising a controller for controlling the scattering structure.

5. A transceiver according to claim 4, wherein the controller controls the scattering structure to modify the eigenmodes formed between the transceiver and a receiver.

6. A transceiver according to claim 4 or 5, wherein the controller receives feedback information from the receiver and uses the feedback information for controlling the scattering structure.

7. A transceiver according to any one of claims 1 to 6, wherein the scattering structure scatters the incident signals by at least one of diffraction, reflection or refraction or use of a wave-guide.

8. A transceiver according to any one of claims 1 to 6, wherein the scattering structure is a diffraction grating.

9. A transceiver according to any one of claims 1 to 8, wherein the scattering structure comprises one or more scattering elements, each associated with one or more of said antennas.

10. A transceiver for use with a second transceiver comprising an antenna array having a plurality of antennas and a scattering structure associated with the antennas for receiving the signals from the antennas, the transceiver having

an antenna array having a plurality of antennas;

feed back means for generating feedback information about the properties of the signals received by the antenna array; and

transmission means for sending said feedback information to said second transceiver for adjusting said scattering structure.

11. A transceiver substantially as hereinbefore described with reference to and as shown in the drawings.

12. A communication system comprising a first transceiver and a second transceiver, the second transceiver comprising:

a second transceiver antenna array having a plurality of antennas;

a scattering structure associated with the antennas for receiving the signals from the antennas; and

a controller for controlling the scattering structure, and the first transceiver comprising:

a first transceiver antenna array having a plurality of antennas;

feed-back means for generating feedback information about the properties of the signals received by the first transceiver antenna array; and

transmission means for sending said feedback information to said second transceiver for adjusting said scattering structure.

13. A communication system including a transceiver according to any one or more of claims 1 to 11.

14. A method of scattering signals produced by an array of antennas, the method comprising:

interposing a scattering structure between the antennas and a receiver to scatter the beams produced by the antennas,

receiving feedback information concerning the strength of the eigenmodes established between the antennas and a receiver; and

adjusting the scattering structure to vary the scattering of the beams produced by the antennas.

15. A method according to claim 14, wherein the scattering structure is a passive structure.

16. A method according to claim 14 or 15, wherein the scattering structure scatters the incident signals by at least one of diffraction, reflection or refraction.

17. A method according to claim 14 or 15, wherein the scattering structure is a diffraction grating

18. A method according to any one of claims 14 to 17, wherein the scattering structure comprises one or more scattering elements, each associated with one or more of said antennas.

19. A method of scattering signals produced by an array of antennas substantially as hereinbefore described with reference to and as shown in the drawings.

20. A transceiver comprising:

an antenna array having a plurality of antennas; and

a scattering structure associated with the antennas for receiving incoming signals and passing them on to the array of antennas.

21. A transceiver according to claim 20, wherein the scattering structure is a passive structure.

22. A transceiver according to claim 20 or 21, wherein the scattering property of the scattering structure can be externally adjusted.

23. A transceiver according to claim 20, 21 or 22, further comprising a controller for controlling the scattering structure.

24. A transceiver according to claim 23, wherein the controller controls the scattering structure to modify the eigenmodes formed between the transceiver and a transmitter.

25. A transceiver according to claim 23 or 24, wherein the controller analyses the received signal and uses the information for controlling the scattering structure.

26. A transceiver according to any one of claims 20 to 25, wherein the scattering structure scatters the incident signals by at least one of diffraction, reflection or refraction or use of a wave-guide.

27. A transceiver according to any one of claims 20 to 25, wherein the scattering structure is a diffraction grating.

28. A transceiver according to any one of claims 20 to 27, wherein the scattering structure comprises one or more scattering elements, each associated with one or more of said antennas.

ABSTRACT:

Method and Apparatus for Increasing the Number of Strong Eigenmodes in a Multiple-Input Multiple-Output (MIMO) Radio Channel

The invention provides a system for implementing a high capacity MIMO system with high throughput which will ensure an eigenmode rich channel largely irrespective of the environment. In conventional MIMO systems, the environment can substantially reduce the theoretically achievable throughput if there is little angular diversity. The system includes a scattering structure for scattering beams emitted by an antenna array to provide good angular diversity at the receiver and hence good throughput in all environments. In addition, the scattering structure is controllable to allow its properties and hence the eigenmodes generated to be varied to maximise the efficiency of the system.

Figure 2

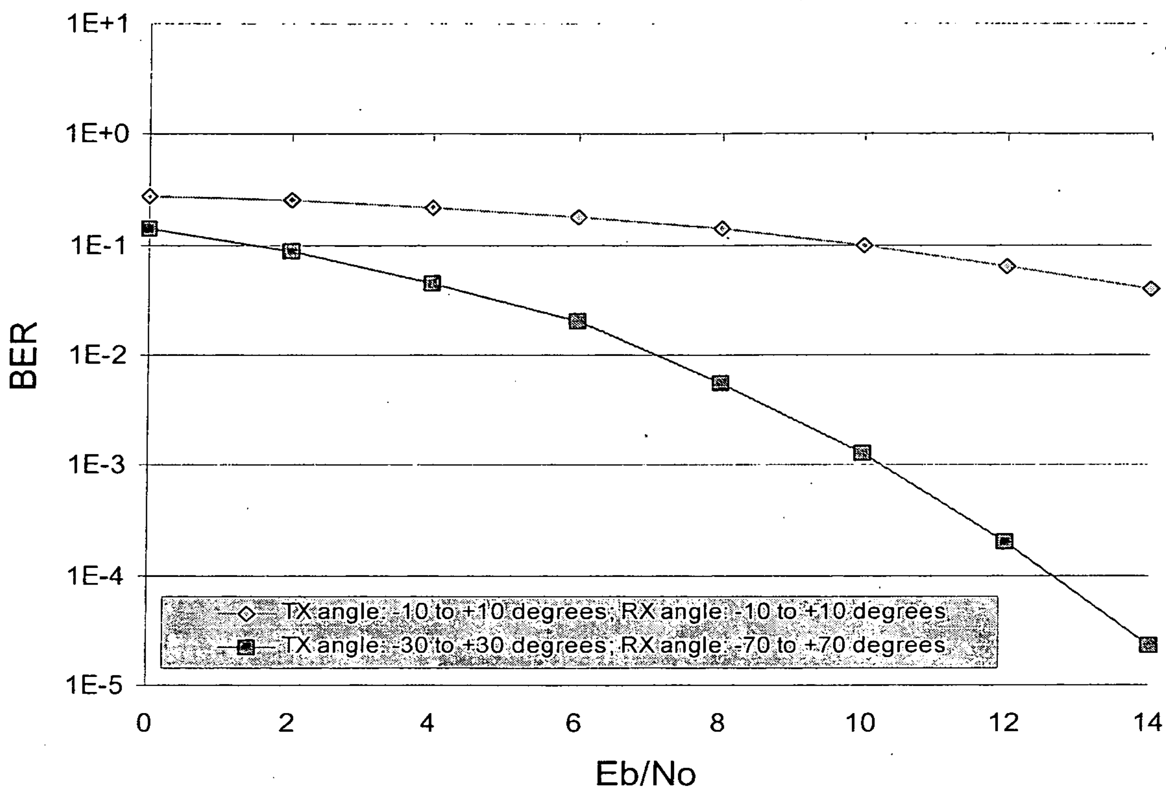
1E+1
1E+0
1E-1
1E-2
1E-3
1E-4
1E-5
BER
0
2
4
6
8
10
12
14
Eb/No
TX angle: -10 to +10 degrees; RX angle: -10 to +10 degrees
TX angle: -30 to +30 degrees; RX angle: -70 to +70 degrees

Figure 1

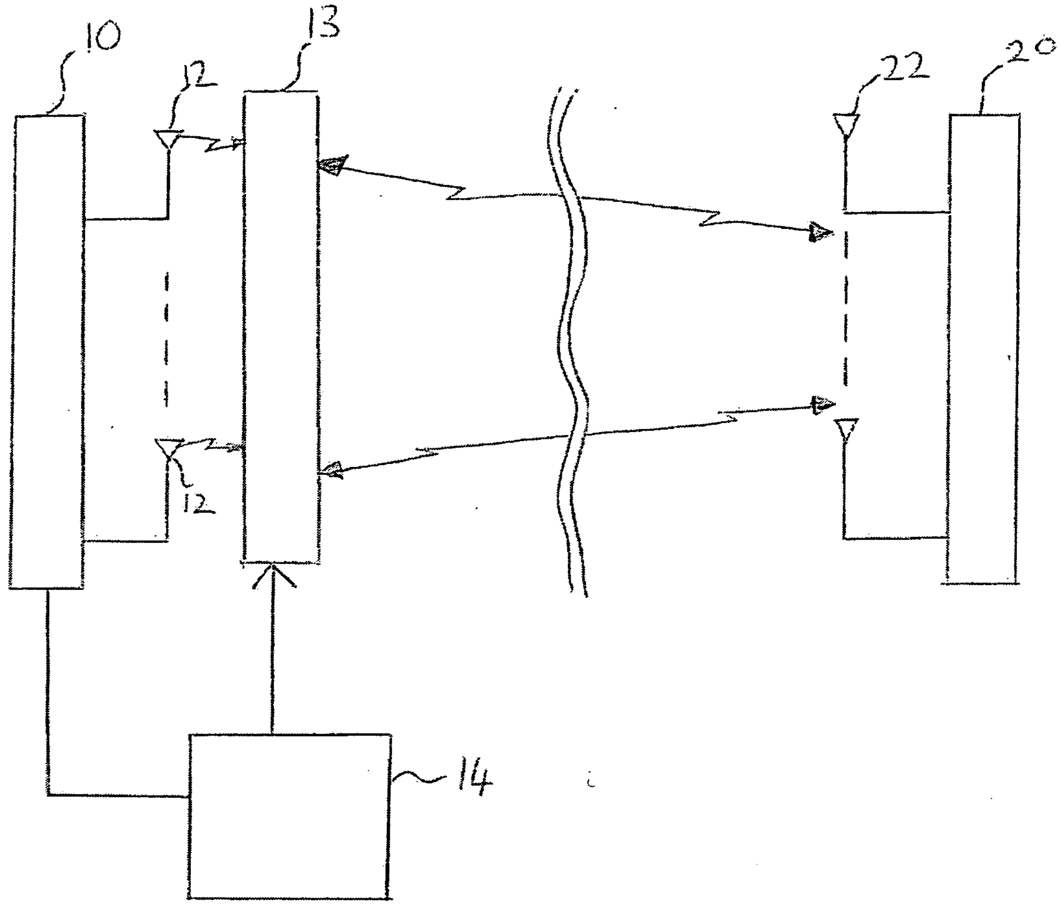

FIGURE 2

22850

703-413-3000

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FILING DATE: November 17, 2003